Experiment on Mobile Light-section Device for Automatic Crack Inspection of Actual-size Tunnel Lining Concrete

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Abstract –

There are approximately 10,000 road tunnels in Japan. Based on the road law enforcement regulations of Japan, human visual inspections of the road tunnels are conducted once every five years. However, presently, the number of inspection engineers is insufficient and the cost incurred for the inspection is significantly high. In conventional crack inspection methods, engineers process many images off site. However, this method requires a lot of effort to identify the cracks and dirt.

We have studied an automatic detection method to determine the crack positions by using high-resolution texture/depth images that are acquired by using the mobile light-section method. In this report, we present the study outline and introduce the prototype of the devices developed. Furthermore, we present the results detected by our method using both concrete test samples and simulated actual-size tunnel lining concrete.

Keywords –

Inspection; Concrete; Depth-image

1 Introduction

The Japanese government decided to periodically inspection the road tunnel once every five years since 2014. In principle, the inspection should be performed by near visual inspection to the tunnel overall length. The results of the inspection and diagnosis were recorded and saved, and a decision was made to classify the diagnostic results of soundness on a unified basis. Against such a background, issues such as a shortage of engineers and lack of budget to inspect road tunnels are becoming apparent [1].

Close visual inspection of a road tunnel is conducted by inspection experts, who observes the surface of the lining concrete in the vicinity using an aerial work platform or the like. The experts measured and recorded the degree of the changes in the cracks and floats, steps, efflorescence, honeycombs, water leakage and the like. The representative method to support the experts is based on an image processing [2]. Often, the method needs off-line image process for a large amount of image data of the concrete lining surface. Because the common method of the image processing recognizes dark pixels with cord-like arrange as the cracks, a dirt or the like can be erroneously detected as a crack. Various methods have been made to prevent these false detections, but some challenges still remain for completely automatic crack detection.

In order to solve these problems, the automatic crack inspection device based on the light-section method have proposed and developed to support close visual inspection. The device is the one of the component of our robot system called “Variable guide frame vehicle” developed for traffic-free tunnel inspection [3]. In this paper, we describe an outline of the device; specifications of the prototype of the device; and the results of the performance verification experiments of the prototype using concrete specimens and simulated actual-size tunnel lining concrete.

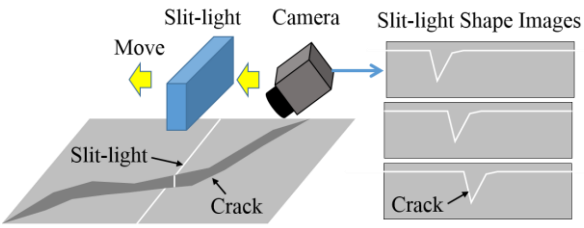

Figure 1. Concept of crack light-section device

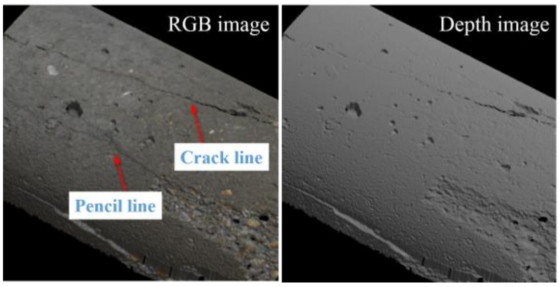

Figure 2. Tunnel inspection test by using our light-section device prototype

2 Mobile Light-section Device Developed

The authors have made it possible to distinguish between cracks and dirt by obtaining a three-dimensional shape of the concrete surface. In various methods to acquire the three-dimensional shape, a light-section method was adopted considering both the high resolution with sub-millimeter order and the portability for wide area inspection over kilometer order.

As shown in Figure 1, the light-section method acquires a three-dimensional shape by causing the slit-light and the area camera to move relative to an object for scanning, while maintaining a certain angle. It is based on the property that the slit-light deforms accordingly. By using the slit-light of a white LED, a color image (visible image) whose coordinates are coincident with the three-dimensional information can be obtained. Figure 2 shows an example of a color image and a depth image obtained by scanning the same object. In the depth image, it is possible to distinguish between real cracks and simulated cracks drawn with pencils.

The authors made a prototype of an automatic concrete crack inspection device that can implement the light-section method by combining the wheel and encoder, and scanning the lining concrete surface (Figure 3, Table 1). The prototype of the image processing software was configured as shown in Figure 4. An image is photographed according to the scanning distance, and the light-section processing is performed when the images are accumulated. Based on the generated depth image and color image, the cracks are automatically detected by the procedure shown in Figure 5, and the detection result is saved. The detection results are integrated for each joint of the structure, and used for the measurement of the crack length and the investigation of the closed cracks that has a risk of chip out to a road. The system was built so that these processes could be done onsite.

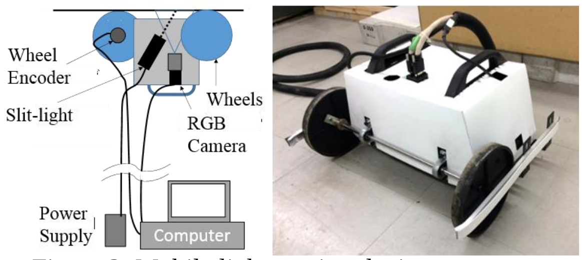

Figure 3. Mobile light-section device prototype

Table 1. Specification of the device

Item	Value	Unit
Size	W410×L414×H242	mm
Weight	6.0	kg
Image Resolution	0.1	mm/pixel
Image Width	200	mm

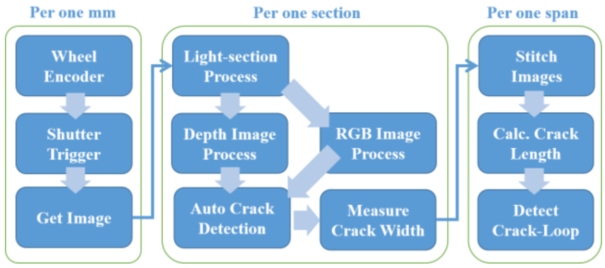

Figure 4. Crack inspection flow by the device

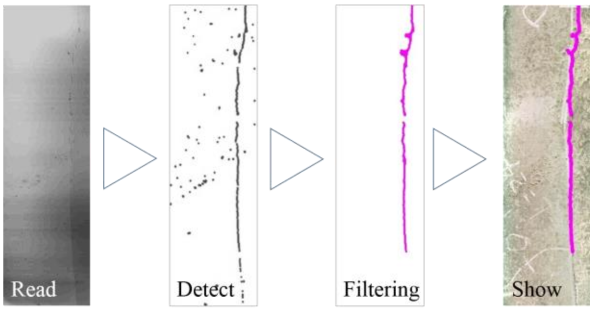

Figure 5. Flowchart of automatic crack detection

3 Test on Concrete Crack Samples

In order to verify the performance of the automatic inspection of cracks by this device, crack inspection of concrete test samples, which cracked owing to bending force, was performed. As shown in Figure 6, the simulated cracks were drawn with felt pen (black, brown and green) and chalk (white) near the actual cracks, and a depth image was obtained using the light-section method. Furthermore, the cracks were detected from the depth image by image processing.

For each of the 10 concrete test samples, the detection rate (the detected crack length dividing by the actual crack length) and the false detection rate (the number of erroneously detected pixels divided by the total number of detected pixels) is shown in Figure 7. For comparison, the results of crack detection using a commercial software and the color images of the concrete test samples are shown in the figure. The detection rate of the cracks using the proposed method was greater than 73% and the false detection rate was less than 8%, both of which were confirmed to be superior to those of the conventional method. The main cause of false detection was surface bubbles near the cracks. However, the misdetection of felt pen or chalk was 0%.

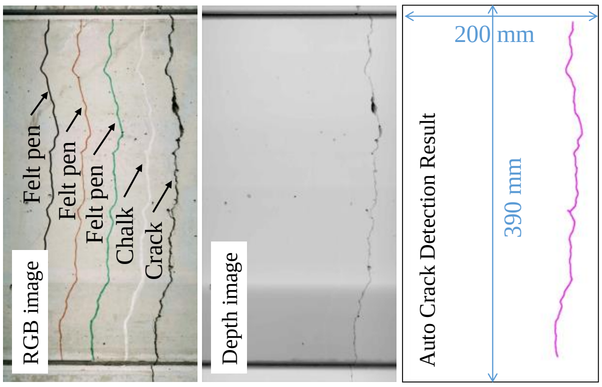

Figure 6. Automatic crack detection result example by using a concrete test sample with simulated dirt lines and a chalk line

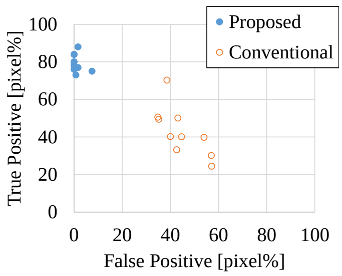

Figure 7. Automatic Crack detection accuracy by using 10 concrete test samples

4 Test on Actual-size Tunnel

The depth image and color image were obtained by scanning the lining concrete surface using the light-section method on the actual-size test tunnel of Japan's Construction Method and Machinery Research Institute (CMI). As shown in Figure 8, manual scanning was performed on an aerial work platform using the prototype of this system. The scan range was ~9.7 m in the circumferential direction of the arch part, as shown in Figure 9, and ~3.0 m in the axial direction. Considering the overlapping portion in the short axis direction, the effective scan width was 150 mm. 69 strips of image were taken and stitched as Figure 10.

Based on the obtained depth image, crack detection software is used to automatically detect the cracked parts from the images of each scan; the width and length of the crack are obtained by counting the detected pixels semi-automatically as shown in Figure 12. This was done by an operator specifying two points on the screen and automatically counting the pixels in a straight line connecting the two points. The width and length of the cracks thus obtained were compared with those obtained using the conventional method (close visual observation) by a skilled checker.

The measurement results of the crack width and the crack length are shown in Figure 13 and 14. When comparing the measured value using the automatic crack inspection device with the close visual inspection results obtained by skilled workers as shown in Figure 11, it was found that the crack width is 4% greater on average, and the crack length is 4% shorter than the values obtained by a skilled worker. The crack widths measured using our automatic method agreed with more than half of the values measured by a skilled worker. In some cases, the width was 0.2 mm greater than the value obtained by a skilled worker, although it was not any problems in practical use.

The crack detection rates are shown in Figure 12. The rate was over 88% when excluding the crack with a width of 0.6 mm. The false-negative crack detection occurred for the crack with an efflorescence (at a red dotted circle in Figure 12). The false-positive occurred due to the joint adjustment near a crack (at blue dotted circles in Figure 12) and concrete honeycombs at several places. Currently, we are investigating ways to distinguish the cracks and honeycombs more clearly using a cord-like structure of the cracks and a circularity of the honeycombs.

Figure 8. Tunnel inspection by using our device on an aerial work platform

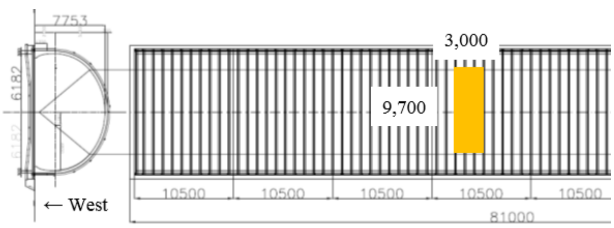

Figure 9. Target area for our visual inspection test in simulated actual-size tunnel of the CMI

Figure 10. Panoramic image of a tunnel lining concrete of the CMI

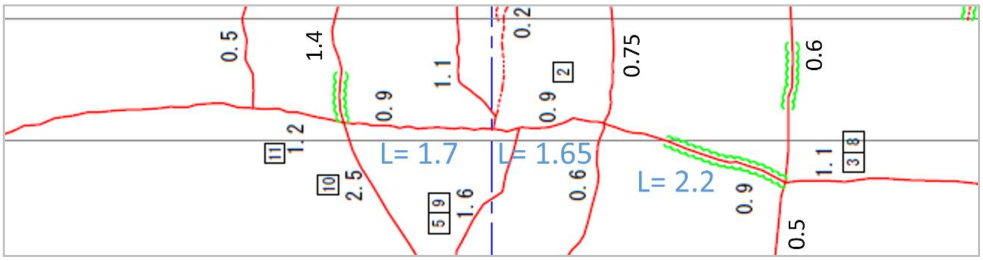

Figure 11. Inspection result by conventional method by inspection experts

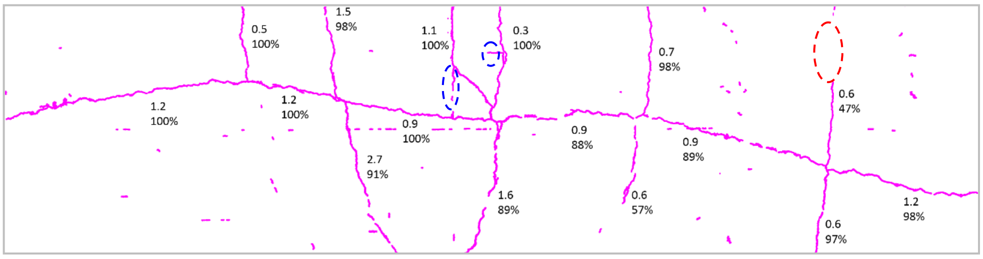

Figure 12. Auto crack detection result with crack width and crack detection rate

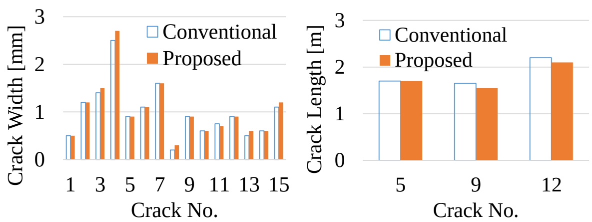

Figure 13. Comparison of crack width and length

5 Conclusions

The overview of the device that automatically detects the crack in the tunnel using the light-section method, and the prototype specifications were described. This device discriminates between cracks and contamination in the concrete test samples Next, we showed that crack detection using depth images is superior to over crack detection using conventional visual images. Furthermore, the report on the detection results of the width and length of cracks in an actual-size tunnel showed that the proposed technique has a crack detection performance equivalent to that of humans.

Currently, the authors are brushing-up the tunnel inspection method using this device for improving the detection accuracy of crack detection software. This will be reported on the future.

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